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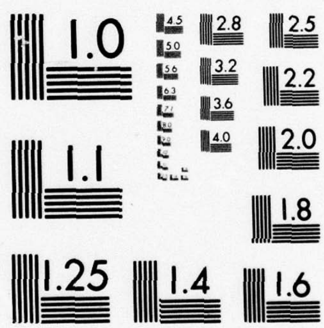

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Technical Note

CEL

TN no. N-1475

title: IN-SITU MEASURING TECHNIQUES FOR PILE LENGTH

author: J. B. Forrest

date: March 1977

sponsor: NAVAL FACILITIES ENGINEERING COMMAND
Pacific Division, FPO San Francisco 96610

program nos: 53-031

CIVIL ENGINEERING LABORATORY

NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. REPORT NUMBER: CEL-TN-1475

2. GOVT ACCESSION NO.: DN687054

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle): (6) IN-SITU MEASURING TECHNIQUES FOR PILE LENGTH.

5. TYPE OF REPORT & PERIOD COVERED: (9) Final rept. Jul [redacted]75 – Jun [redacted]76,

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s): (10) J. B. Forrest

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS:
Civil Engineering Laboratory
Naval Construction Battalion Center
Port Hueneme, California 93043

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: O&M, N 53-031

11. CONTROLLING OFFICE NAME AND ADDRESS:
Naval Facilities Engineering Command, Pacific Division
FPO San Francisco 96610

12. REPORT DATE: (11) Mar[redacted]1977

13. NUMBER OF PAGES: 26 (12) 25p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report): Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Pile length, in-situ measurements, non-destructive testing, sonic techniques.

391 111

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes an investigation of procedures for determining in-situ the length of foundation or sheet piles. Two techniques were evaluated, one based upon the reflection of sonic energy, and the other upon sensing the electromagnetic flux field that builds up around ferrous objects in the earth's magnetic field. The sonic technique was found to operate satisfactorily within limits on piles made of steel, concrete, and wood, both with the tops

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Civil Engineering Laboratory
IN-SITU MEASURING TECHNIQUES FOR PILE LENGTH
(Final), by J. B. Forrest

TN-1475 | 26 pp illus | March 1977 | Unclassified

1. Bearing piles | 2. Sonic detection | I. 53-031

This report describes an investigation of procedures for determining in-situ the length of foundation or sheet piles. Two techniques were evaluated, one based upon the reflection of sonic energy, and the other upon sensing the electromagnetic flux field that builds up around ferrous objects in the earth's magnetic field. The sonic technique was found to operate satisfactorily within limits on piles made of steel, concrete, and wood, both with the tops exposed and with the tops encased in a concrete decking. The electromagnetic flux-sensing method involves inserting a probe into the soil in the vicinity of the pile. This method appears to be satisfactory for locating tips of ferrous metal piles either in situations where the probe can be jetted into the ground or where it can be inserted into a pre-drilled hole.

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CONTENTS

INTRODUCTION

In cases where records of waterfront structures, including piers, wharves, bridges, quay walls, etc., are lost or destroyed, no data are available on the lengths of piling and other foundation supports [1, 2]. Such data are necessary before any new construction can be designed or any adjacent harbor or channel can be dredged to permit passage of ships of increased draft. Since piling extends from above the waterline to some distance below the submerged soil surface or mudline, the determination of pile lengths has traditionally been very slow and expensive, and, in the case where divers are required, hazardous as well.

This report is concerned with the evaluation of techniques for conducting in-situ pile length measurements. Two approaches were investigated, one based upon sonic or wave propagation techniques, and the other upon direct-probing methods. Each approach was narrowed down to what appeared to be the single most promising technique within its respective family. In the case of the sonic techniques, the best-developed approach that could be located was patented by a government employee at the Naval Shipyard (NSY) at Mare Island, California.* For the direct-probing approach, no commercially available devices could be located at the time of this writing; therefore, a simple device was developed. This latter device works on the basis of detecting magnetic flux gradients and, therefore, is applicable only to ferrous metal pilings. An analogous device, but one utilizing an induced alternating electric field, has been suggested in Reference 3. Although this latter device offers some advantages over one relying upon a naturally occurring signal, it requires access to the pile for power input; therefore, it will not be considered further.

TECHNIQUES CONSIDERED

Sonic Wave Propagation Methods

Sonic or stress wave propagation methods for determining the characteristics of in-situ piles, while conceptually simple, have not always been completely successful [4]. Nevertheless, the potential of wave propagation methods has been proven both in the laboratory and the field, not only for determining pile lengths but also for the detection

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*The U.S. Government has the right to use and manufacture this device for Government purposes.

of flaws and discontinuities [5]. A major difficulty encountered in utilizing wave propagation techniques is recognizing or interpreting the various reflected signals. This is somewhat related to the ability to control the amplitude and nature of the input signals.

Stress waves in piles can be of the classic body wave types, such as dilatational (P waves) or shear waves (S waves), or they can be surface waves, such as Rayleigh Waves. The energy density or amplitude of classical body waves attenuates at a rate proportional to $1/r$ within the interior of an unbounded medium (r is the distance from the wave source to the point of interest). However, at the surface these body waves attenuate at the rate of $1/r^2$. Rayleigh surface waves, on the other hand, attenuate at a rate of only $1/\sqrt{r}$. Therefore, normal body waves attenuate very rapidly in long piles, and the most predominant wave group velocity is one that is very close to that of the rod wave, which propagates longitudinally with a velocity equal to $\sqrt{E/P}$, where E is Young's modulus for the material, and P is its mass density. This is considered the fastest possible internal wave in a pile [6].

When signals are applied to a pile with a frequency whose wave length is approximately equal to twice the diameter of the pile, the group velocity of the first axisymmetric mode of shear wave response may also become apparent. This wave propagates at a slower velocity, generally slightly above that of the shear wave velocity, $\sqrt{G/P}$, where G is the shear modulus or modulus of rigidity of the material, and P is its mass density.

Thus, since different waves travel at different velocities, any determination of distance, based upon propagation time, must monitor a specific wave type. When a stress pulse is produced by a hammer blow, there is little control over the division of energy that is imparted to the pile in the various mode forms. In addition, when one type of wave impinges upon a boundary or interface, both reflection and transmission of other types of waves can occur that can cause attenuation and distortion of the wave signals of interest. This, for example, can occur when generated surface waves traverse back and forth across one end surface of the pile and make the return of the reflected wave from the far end. Fortunately the rod wave group velocity is generally the most predominant. Nevertheless, control of the form of the input energy is extremely desirable.

Various simplified techniques have been used for controlling the shape of the stress pulse to aid in identifying the reflection of interest. These techniques include impacting with projectiles of defined geometry, such as steel spheres, or with rods of prescribed lengths, etc.

Imperfections or anomalies in the test rod that are too minor to generate distinguishable reflections can appear to increase the apparent wave transfer times [5] and, thus, could lead to errors in distance calculations.

The measurement of pile lengths by sonic or stress wave techniques requires an output display that (1) permits identification of the reflections of interest and (2) also provides the necessary degree of resolution with regard to travel times. The velocity of rod waves has been measured at about 16,000 fps in both steel and aluminum and at about 13,000 fps in concrete and timber. Therefore, measurements with an accuracy of about one foot require a display system with time increments as small as 0.15 ms. This is

approximately the time required for the wave to traverse one foot in the medium and return (a total distance of 2 feet).

When the test pile is confined within another medium, such as soil, the attenuation and dispersion rates are increased due to the radiation of energy to the surrounding medium. Thus, even with considerable input energy, the first reflection from an input pulse may be difficult to discern. This may require the filtering of higher frequency surface waves or extraneous noise signals so as not to mask the initial reflection of the compression wave from the lower end. An alternative would be to generate a pulse in a manner that induces negligible surface waves or extraneous signals.

The shape of the point of contact between the oscillator and the test member can also be important. For example, a rounded tip [7] gives longer contact time than flat ends. The attenuation rate can sometimes be used to indicate the soundness of a member where the length is known and several reflections are observable. Soft inclusions or breaks result in attenuation rates well in excess of those for sound members. The attenuation rate can be measured in terms of ratio of initial input pulse amplitude to amplitude of the reflections at some specified time. The attenuation rate measured in this way is generally noted to be nonlinear, i.e., increasing with time. It appears to be drastically nonlinear with seriously impaired members.

The sonic test apparatus considered most pertinent for the present investigation was one developed by Mr. Paul Minasian,* an employee at the U.S. Naval Shipyard (NSY) at Mare Island, California. This device has reputedly been successful in determining in-situ pile lengths at other locations, such as NSY Mare Island, and Apra Harbor, Guam.

The test apparatus consists of a sonic input source (Figure 1) coupled with a cathode ray tube (CRT) oscilloscope to display the output. This device uses a 110-volt electric power source (capable of supplying up to 10 amperes) to operate a pulse generator, which in turn drives an ammonium dihydrogen phosphate crystal array. This array transmits pulsed mechanical energy either directly into a pile or to a steel shaft that is firmly coupled to the pile by means of an accoustically conductive fluid. The transducer can induce sonic energy into the pile through a concrete capping or cover that is integrally connected to the pile top (Figure 1). The pulse generator, which is also connected to the receiver indicator (CRT display), provides energy to the transducer at a frequency of about 12 kHz, and it includes a gate that passes about 60 pulses per second, each of 2- to 4-ms duration. The pulse generator is capable of operating at energy levels of up to 1,000 watts. The pulse from the crystal oscillator is used to trigger the oscilloscope sweep. The reflected pulse returning to the transducer induces a signal that is amplified and displayed on the oscilloscope. This permits determination of the travel time between the arrival of the incident and reflected pulses.

The readout CRT has gradations equivalent to time increments of approximately 0.4 ms. The ability to interpolate between these gradations appears to be dependent upon the skill of the operator and the clarity of the signal of interest compared to extraneous noise.

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* Patent No. 3,208,177.

The output display will be discussed herein only in terms of the sonic wave propagation time, as interpreted by the operator, Mr. Minasian, without further reference to the interpretation involved in arriving at these propagation times. It is also outside the scope of this report to provide information on the cost of this device, other than to state that the sonic wave generator could be expected to cost several thousand dollars.

Direct-Probing Methods

It was considered desirable to investigate probing devices that locate the tips of steel piling directly for cases where the pile tops are inaccessible to sonic signals. For this approach a device was developed that is sensitive to the variations in electromagnetic flux density that occur near the boundaries of ferrous metal objects that have remained stationary for some time in the earth's magnetic field.

The earth has a magnetic field resembling that of a bar magnet with its axis oriented close to the axis of rotation of the earth. The intensity of this field varies between roughly 36,000 and 70,000 gammas, where a gamma* is a unit defined in terms of the force that the earth's magnetic field will exert on a standard magnet. Ferrous materials become magnetized by this magnetic field, and act as bar magnets aligned with this external field, that is, along the direction of magnetization. Thus, the magnetizing field becomes stronger along the direction of magnetization than it would be in the absence of the magnetized material. However, where the direction of magnetization from the secondary field of the ferrous body opposes the direction of magnetization of the earth's field, these fields tend to cancel each other. These changes in magnetic intensity are commonly used in prospecting for minerals, and are influenced by such things as magnetic susceptibility of the material, long-term changes in the orientation of the earth's magnetic field, etc.

Magnetometers, which take measurements on a much cruder scale, can be used to detect the presence of small ferrous metal objects, such as concealed survey monuments, manhole covers, etc. It is this application that is of interest here.

The instrument used is a modified "Heliflux Magnetic Locator, Model GA-32," purchased from Schonstedt Instrument Company of Reston, Virginia. This instrument has two magnetic-field sensors (flux gates) spaced about 20 inches apart within the sensor (Figure 2). When the sensor is exposed to a uniform magnetic field, such as that of the earth, the voltage generated by one sensor is balanced by that generated by the other. When a concentration of magnetic flux lines is approached, such as when the sensor approaches the edge of a ferrous object, one sensor experiences a greater magnetic field than the other. The output voltage, no longer balanced, causes an increase in the frequency (normally 65 Hertz when in balance) of the output signal. For this investigation the output signal was monitored by audio means, using a pair of headphones. (A visual milliameter output has since been improvised and appears to be much more satisfactory.)

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*1 gamma is equal to 10^{-5} gauss, where a gauss is a cgs unit of magnetic induction.

The sensor package for this instrument has been encapsulated into an aluminum (nonferrous) probe (Figure 3) so that it can be jetted into the soil. This probe consists of a 5-foot-long, 2-1/2-inch-diameter aluminum pipe jacket with a chopping bit affixed at one end to aid in penetration and a connection at the other end to permit coupling to a standard "A" size drilling rod. The sensor is potted in position with a silicone rubber potting compound (Sylgard 184 from Dow Corning). An enclosed 1-inch-diameter aluminum pipe conducts high-pressure water, which comes from a surface water pump, from the "A" rod to the chopping bit to aid penetration of the probe through a jetting action. The sensor package is connected to the surface readout (for the case of this investigation, a frequency-modulated (FM) audio signal device) by means of an armored cable.

When the probe is aligned in a direction parallel to a steel pile and at some distance in from the ends, both enclosed sensors experience the same uniform flux field generated by the pile (up to about 10^6 gammas, or about 20 times that of the earth's magnetic field). As the probe is advanced along the pile, in the region of roughly parallel flux lines, both sensors experience similar flux density. As the sensors approach the end of the pile, however, the leading sensor intrudes into the region of rapidly changing flux density (Figure 4) and the unbalance results in a change in the output signal.

FIELD MEASUREMENTS

Site Descriptions

Field pile length measurements were carried out at four locations. Three of these were at Hunters Point in San Francisco, a deactivated Naval shipyard, and the fourth was at a refueling pier undergoing reconstruction at the Naval facility at Point Molate, near Richmond, California. Three types of piles were investigated: steel sheet piles, with the tops exposed and with the tops embedded in a concrete deck; gunite-coated timber piles; and prestressed concrete piles.

A plan view of the sites at Hunters Point is shown in Figure 5. At Sites 1 and 2 (Figures 6 and 7) steel sheet pile cells containing hydraulic sand fill were constructed during the mid-1940s. The sheet piles in the front walls of the cells, which are the piles of interest to this study, are MP 113s with arch web sections. These piles had an original web thickness of 1/2 inch, a design length of 76 feet, and a design penetration depth of 20 feet beneath the harbor dredgeline. The design dredgeline was about 57 feet beneath the deck level. However, the present mudline appears to be about 20 feet higher than this. The driving records [8] indicate difficult driving conditions into a very stiff sandy clay. This clay was apparently overlain by about 7-1/2 feet of very dense sand at about the original design dredge level.

The condition of the sheet piles is very bad, with some holes corroded completely through the steel webs. All interlocks are corroded together, and the pile tops, where

exposed, are rough and rusty. It was necessary to file flat surfaces on the uneven pile tops to permit coupling between them and the sonic energy device. In some locations, the sheet piling had been covered with a concrete slab about one foot thick. The concrete deck has a very rough texture, and the degree of embedment of the underlying sheet piles is unknown.

Site 3 is located at the beginning of Pier No. 1 (Figures 5 and 8). This pier was constructed with an 11-inch-thick concrete deck, supported on gunite-coated timber piles. Driving records and cut-off lengths for the timber piles are known, but their degree of embedment into the concrete pile caps and into the beams supporting the concrete deck are unknown.

Site 4, located at Point Molate, provided two different sizes of new, prestressed concrete piles. One group were 12-inch-square, in cross section, concrete piles with exposed tops (i.e., they had not yet been tied into the structure), and the others were 18-inch-square concrete piles terminating at the top in 30-inch-thick concrete pile caps. In the latter case, the pile caps connected groups of eight piles, some vertical and some at a batter, with pile tips at elevations about 125 feet below the cap. It is apparent that the large concrete mass involved could provide a tremendous energy absorption capability, thereby causing difficulties in sonic measurement of pile length.

Sonic Test Data

<u>Site 1.</u> This site is located in Berth 29, Cell 132 (Figure 5). Sonic measurements were carried out on several exposed sheet piles near the center of the cell by placing the sonic energy source on the pile tops. The measurements are presented below, and all results are summarized in Table 1.

Pile No. 1: Inadequate coupling was obtained between the transducer and the top edge of sheet pile. This was probably due to the severely corroded state of the pile, and was further affected by the relatively thin pile section available for making contact with the base of the sonic oscillator.

Pile No. 2: Reading 0.88 ms travel time.

Pile No. 3: Adequate coupling could not be obtained.

Pile No. 4: Reading 0.88 ms travel time.

Pile No. 5: Adequate coupling could not be obtained.

Assuming a wave velocity in the steel piling of about 16,000 fps, this would provide a round-trip distance of 141 feet or a pile length of 70-1/2 feet. By assuming a propagation velocity of 17,300 fps, the design length of 76 feet would be determined. This high a velocity in piling of this condition is unlikely. On the other hand, the reference to hard driving into the dense clay and the lack of actual driving records raise the possibility of the piles being shorter than the design length.

Site 2. This site is located in Berth 21, Cell 104. Sonic measurements were carried out on several uncapped sheet piles near the intersection of Cells 104 and 105 and under the concrete slab near the center of the front wall of Cell 104.

Pile No. 6: With the sonic oscillator placed directly on top of the sheet pile, a time interval of about 0.96 ms was indicated.

Pile No. 7: Same as above.

Pile No. 8: This pile was beneath an approximately 12-inch-thick concrete deck. With the transducer situated on the deck surface, adequate coupling could not be achieved for taking sonic measurements.

Pile No. 9: Same situation as Pile No. 8, but a propagation interval of 0.96 ms was indicated.

Pile No. 10: Similar to Pile No. 9.

Pile No. 11: Similar to Pile No. 9.

Assuming a wave velocity in the sheet piling of about 16,000 fps, a double length of 154 feet or a pile length of 77 feet would be calculated. This agrees very closely with the design length of the concrete-covered piles (if one allows for the time of propagation through the concrete deck into the steel pile), and it differs only by 1 foot for the exposed piles. Unfortunately, a record of the actual driven lengths of the individual piles was not available.

Site 3. This site was located at the base of Finger Pier No. 1 (Figures 5 and 8). Sonic measurements were taken on the concrete deck directly over several gunite-encased, treated timber piles. The tops of these piles were embedded in either pile caps (two piles per cap) or support beams, making a total concrete thickness of about two feet. The gunite casing on the piles was about two to three inches thick and was reinforced by no. 8 gage steel wire mesh. This cover presumably extended to below the mudline, which, at the time of the investigation, was about 35 feet below the deck. The sonic wave velocity in the piles, as ascertained by correlating the depth to the mudline (determined by sounding) with the mudline position as indicated on the CRT output, appeared to be about 12,000 fps. Unfortunately, the reflection interpreted on the CRT output as the mudline would presumably be returned from the depth at which the pile first obtained a measure of confinement and support. This could be expected to be below the mudline horizon as obtained by sounding. Thus, it would appear that the propagation velocity is faster than 12,000 fps. Since the depth of concrete overlying the pile is not known precisely, no correction was made for this. Readings were obtained as follows:

Pile No. 12: (Pile No. 1K, located at the west corner of Pier No. 1.) With the oscillator placed upon the concrete deck (over the pile), the time interval for return of the signal pulse was 1.29 ms. This pile had a recorded driven length of 92 feet, thus suggesting a propagation velocity of about 14,300 fps.

Pile No. 13: (Pile No. 2K, just northeast of Pile No. 12.) A time interval of 1.21 ms was indicated. Since the driven length of this pile was known to be 95 feet, then a propagation velocity of about 15,700 fps is suggested.

Pile No. 14: (Pile No. 29 at north corner of Pier No. 1.) A time interval of about 1.26 ms was indicated, suggesting a propagation velocity of 14,600 fps for the 92-foot driven pile.

Unfortunately, it cannot be ascertained whether the apparent differences in the velocity measurements for the three concrete-encapsulated piles are due to difficulties in record interpretation, differences in concrete capping details, or other factors.

Site 4. This is the site of the refueling pier under reconstruction at Point Molate. Sonic measurements were carried out by placing the crystal oscillator in direct contact with the top of two 12-inch-square prestressed concrete piles (eight prestressing tendons enclosed within spiral reinforcing). Measurements were also attempted by placing the oscillator on pile caps supported by 18-inch-square prestressed concrete piles.

Pile No. 15: With the transducer placed on top of the 12-inch-square pile, the measured transmission time was 1.13 ms, which would suggest, at an assumed velocity of 13,000 fps, a pile length of 73-1/2 feet. This compares to a driven length of 76-1/2 feet.

Pile No. 16: With the oscillator on top of the 12-inch-square pile, a propagation time increment 1.13 ms was indicated.

Pile No. 17: The oscillator was placed upon the massive pile cap, with an attempt to situate it directly over the vertical 18-inch-square pile. A signal that was interpreted as the mudline (when compared to the mudline by sounding) suggested a propagation velocity in the piles of about 13,000 fps in the pile. A major reflection was returned that suggested a major change at about 73 feet down (based upon a propagation velocity of 13,000 fps). However, no significant reflections were obtained from below this level, which suggests no major changes beyond this depth. The driven pile length in this case was 126 feet.

Pile No. 18: This one was similar to Pile No. 17. A very small reflected signal was noted for a depth corresponding to about 111 feet down, but nothing significant was observed beyond a depth of about 73 feet.

It would appear that for Piles 17 and 18 almost all the sonic energy is absorbed beyond a depth of about 73 feet. It is reasonable to assume that the massiveness of this concrete-capped-pile structure would result in attenuation levels high enough to impair the reflection of sonic energy from large depths, particularly in highly competent materials.

Magnetometer Probe Investigations

The magnetometer probe was first tested for its ability to detect the boundaries of ferrous metal objects in air. Under these conditions the probe was capable of detecting the ends of steel piles or the edges of metal sheets, etc., within an accuracy of 1 foot at spacings of about 0 to 3 feet away.

In order to validate the probe's capability in sediments, measurements were attempted at various locations at both Site 1 (Cells 131 and 132) and Site 2 (Cell 104) (Figure 5). Unfortunately, due to the very stiff, sandy clay encountered at depths of about 55 feet, it was impossible to advance the probe beyond these depths, even with pressure-jetting. A combination of chopping and jetting might have achieved some additional penetration, but the nature of the in-situ deposits was such that this would not have been sufficient to reach the pile tips. In spite of the unsuccessful attempt to reach the pile tips the probe appeared to perform adequately, and it did not have its performance impaired even under these rather difficult penetration conditions. Changes in response were noted throughout the major length of the piles, suggesting numerous holes or irregularities. These magnetic irregularities were especially noticeable just above the design dredgeline, suggesting either unusually high deterioration at this level or the presence of other ferrous objects. The output generally appeared comparatively quiet (no large flux gradients) at depths just below the original dredgelines. The tops of the sheet piling were clearly recognizable by increased output signals whenever the probe was lowered or retrieved through the zone near the pile tops.

SUMMARY

On the basis of a limited number of field trials, two devices for measuring the lengths of piles in-situ have been found to function within limits. The more general and potentially valuable device, which is based upon sonic wave propagation techniques, has shown a capability for indicating the lengths of steel, concrete, and timber piles under several situations, assuming the wave propagation velocity is known or can be determined in advance.

It must be emphasized that pile length determinations by sonic means cannot have an accuracy greater than the accuracy with which the propagation velocity of the sonic waves are known. For example, concrete piles (although generally in the range of 12,000 to 14,000 fps) could conceivably have a sonic propagation velocity of 13,000 ± 3,000 fps. Thus, measured pile lengths, in the absence of actual velocity information, could, at least theoretically, be plus or minus almost 25 percent.

Unfortunately, the expertise required and the accuracy obtainable in interpreting the readout signals cannot, for proprietary reasons, be treated specifically within this report. Nevertheless, it is evident that the answers to these questions are strongly tied in with the

geometry of the test situation. Under ideal conditions, such as that of a sound pile inserted into a much softer, uniform medium, this sonic device would provide length determination with a minimum of operator interpretational skill. On the other hand, under less ideal conditions, such as those where several very long piles terminate in pile caps or other large masses, the reflected signals could be impossible to interpret or even misleading. It is obvious that the more information known by the investigator in advance, such as in what region on the output trace one would expect to find the reflection of interest, the more successful would be his interpretations.

The magnetometer probe treated in this report could not be irrefutably validated because of the nature of the subsurface soils, i.e., very stiff clay that prohibited inserting the probe to the depths of the pile tips. However, it appeared to work in principle. It is apparent that in medium to loose cohesionless soils this probe would permit one to determine the ends of driven steel piling. In regions of stiff clay, which are not amenable to jetting, some form of preboring would be necessary. It was also apparent that the frequency-modulated audio signal of the output device is coarser than is desirable for this application. A visual readout scale that can be evaluated quantitatively has been devised, and appears to be considerably more reliable.

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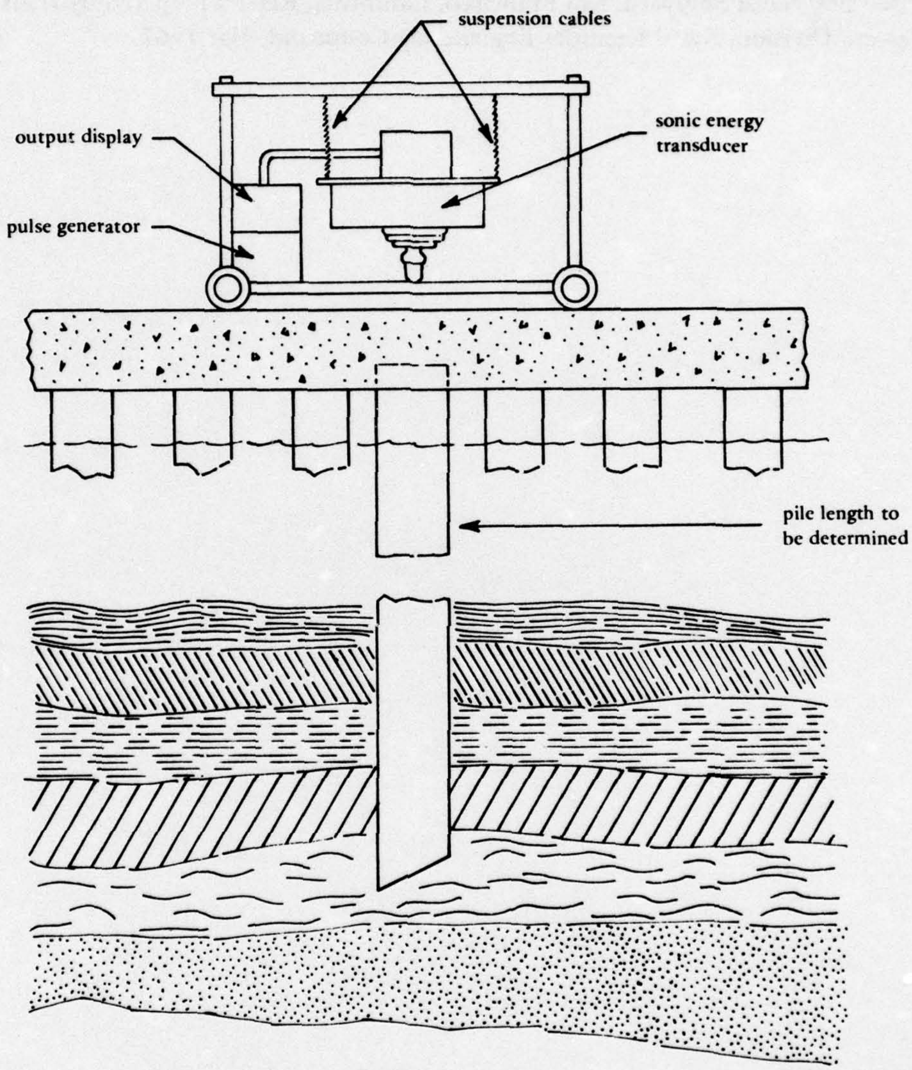

Figure 1. Schematic of pile length determining device.

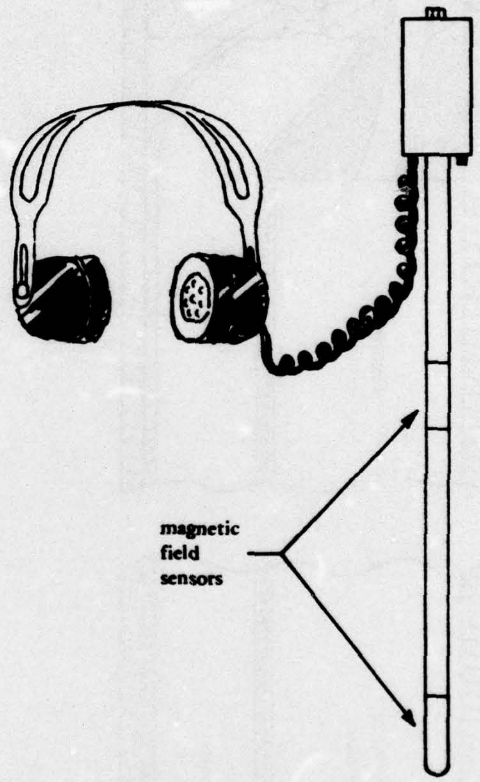

Figure 2. Heliflux Magnetic Locator.

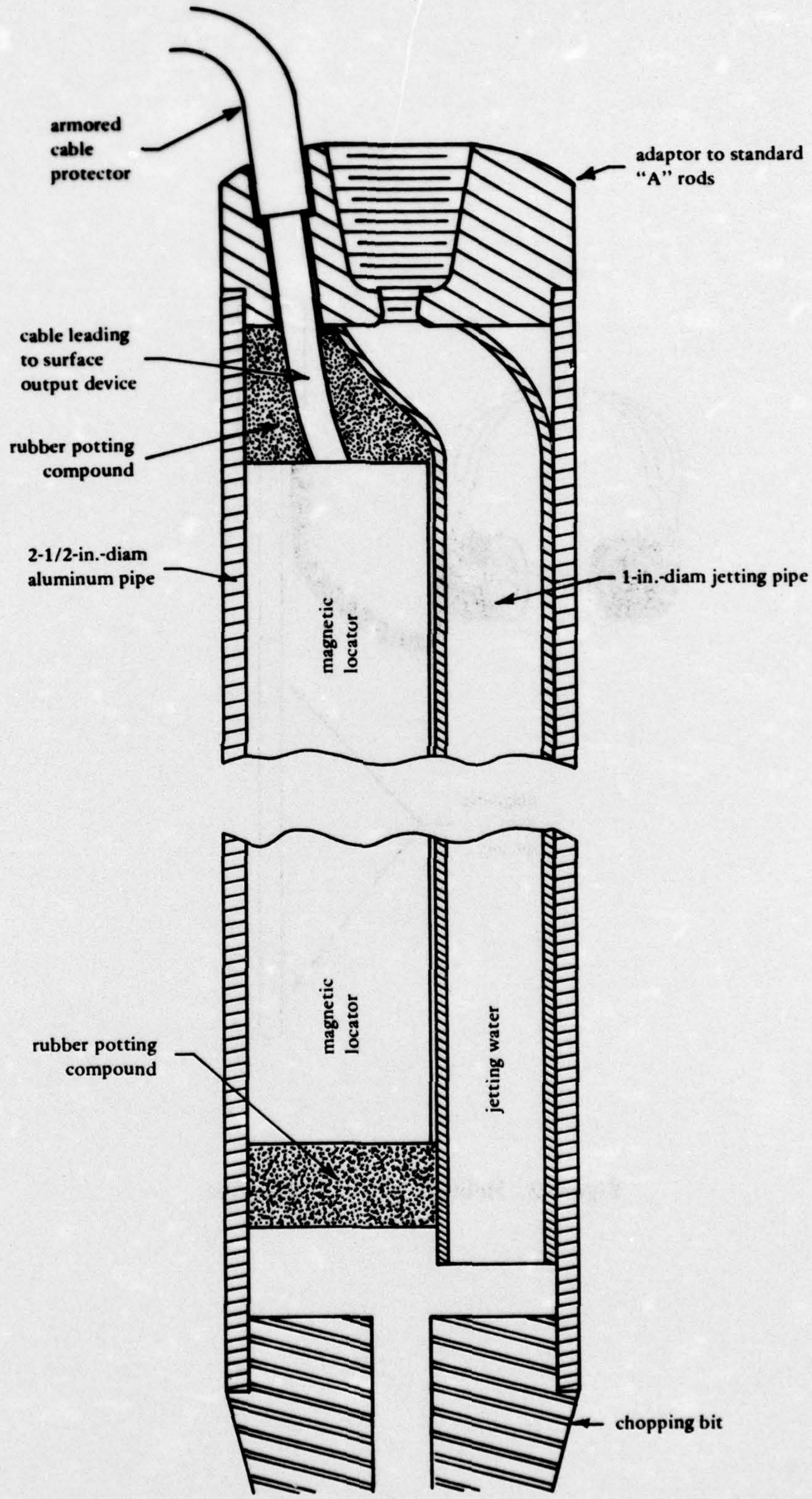

Figure 3. Magnetometer probe.

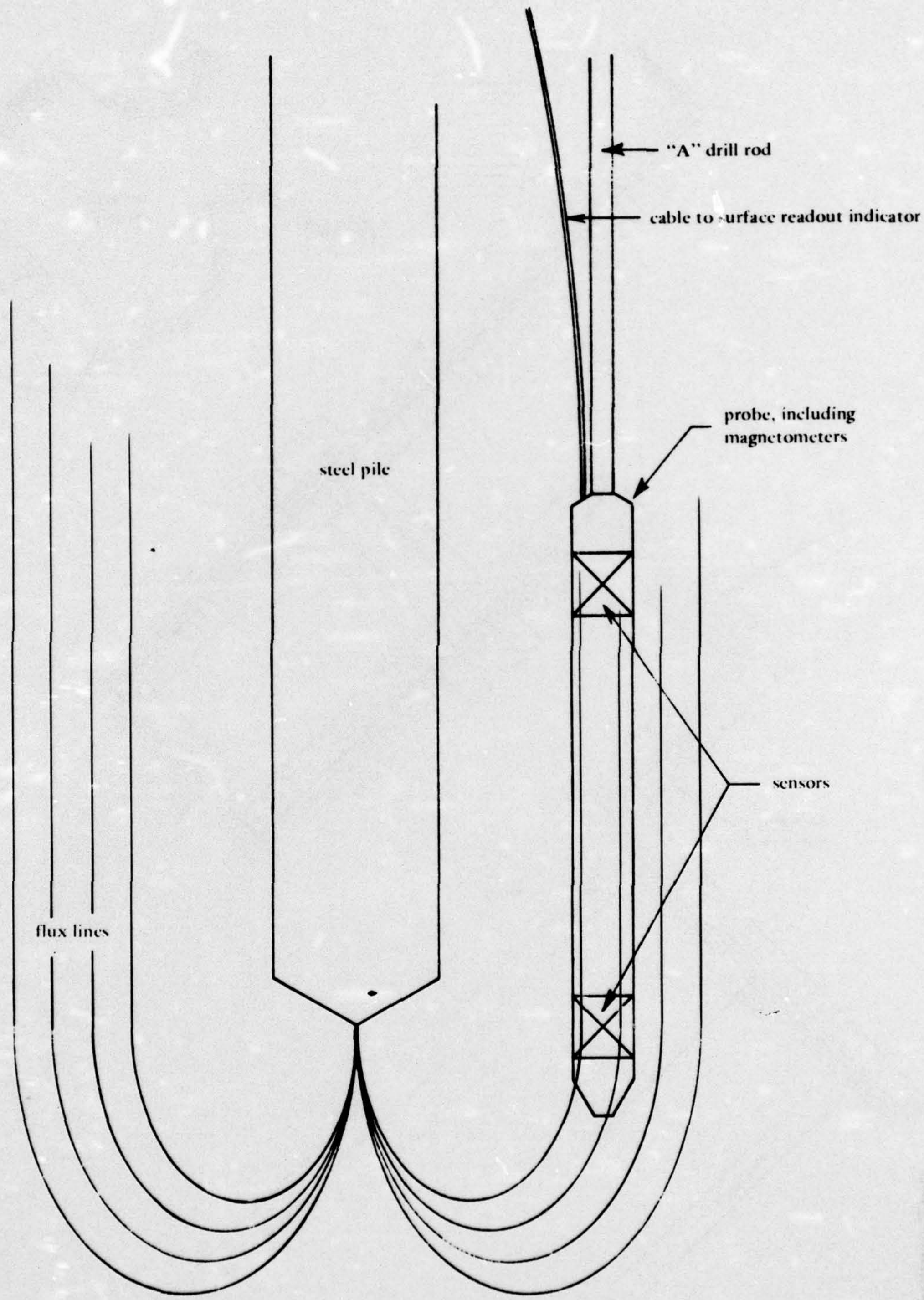

Figure 4. Magnetometer probe sensing pile tip.

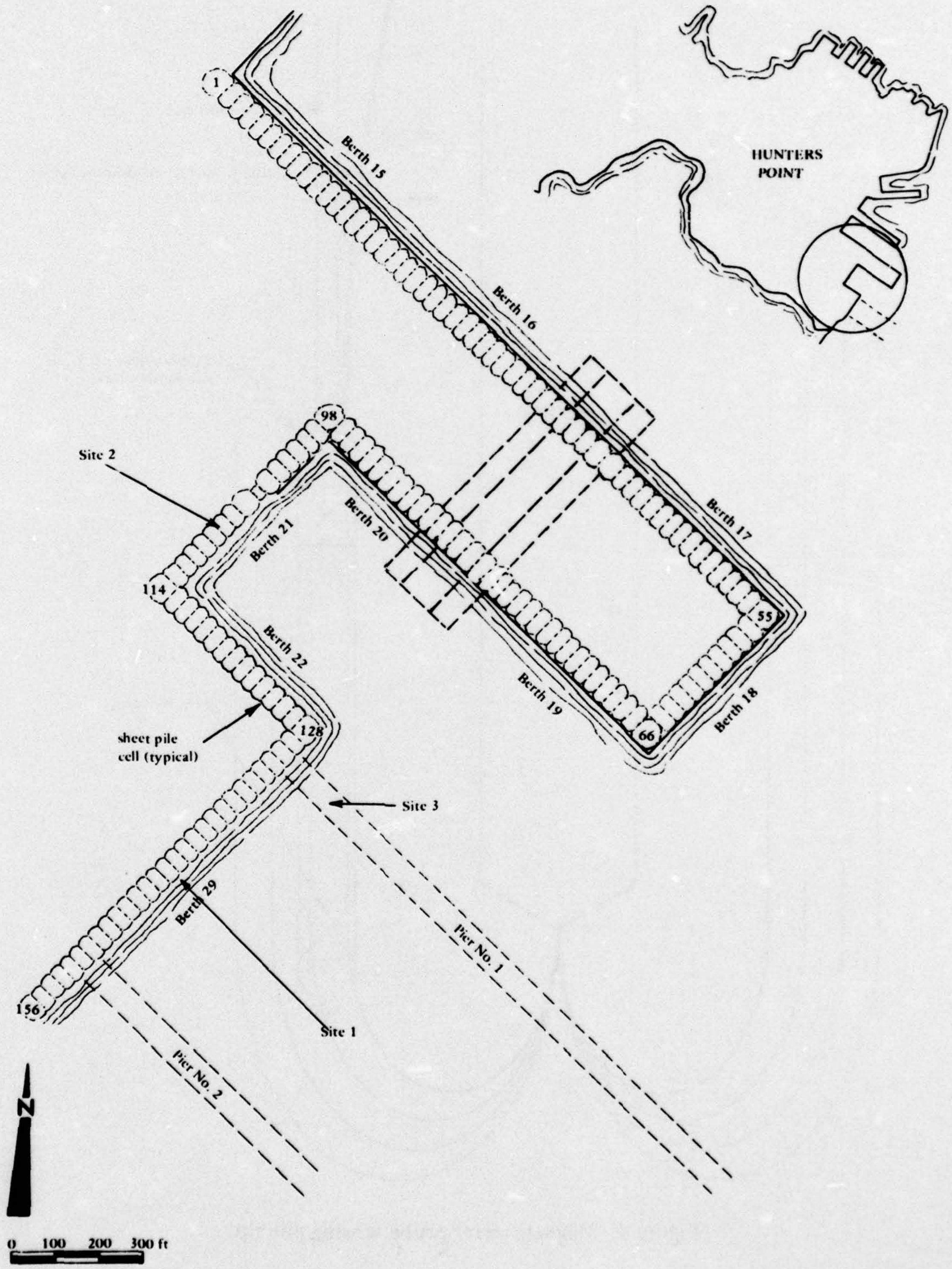

Figure 5. Plan view of test sites at Hunters Point.

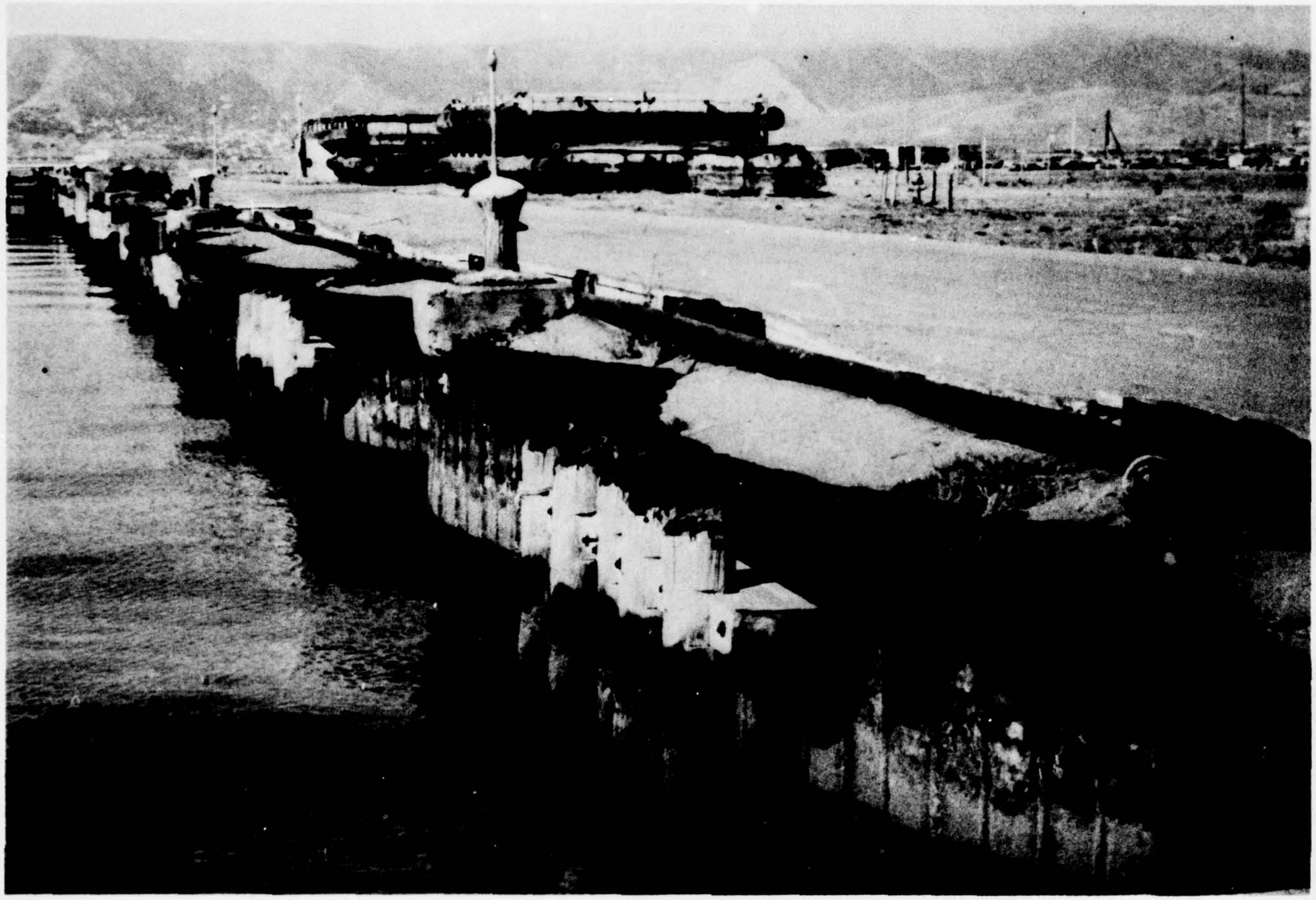

Figure 6. Sheet pile cells at Site 1.

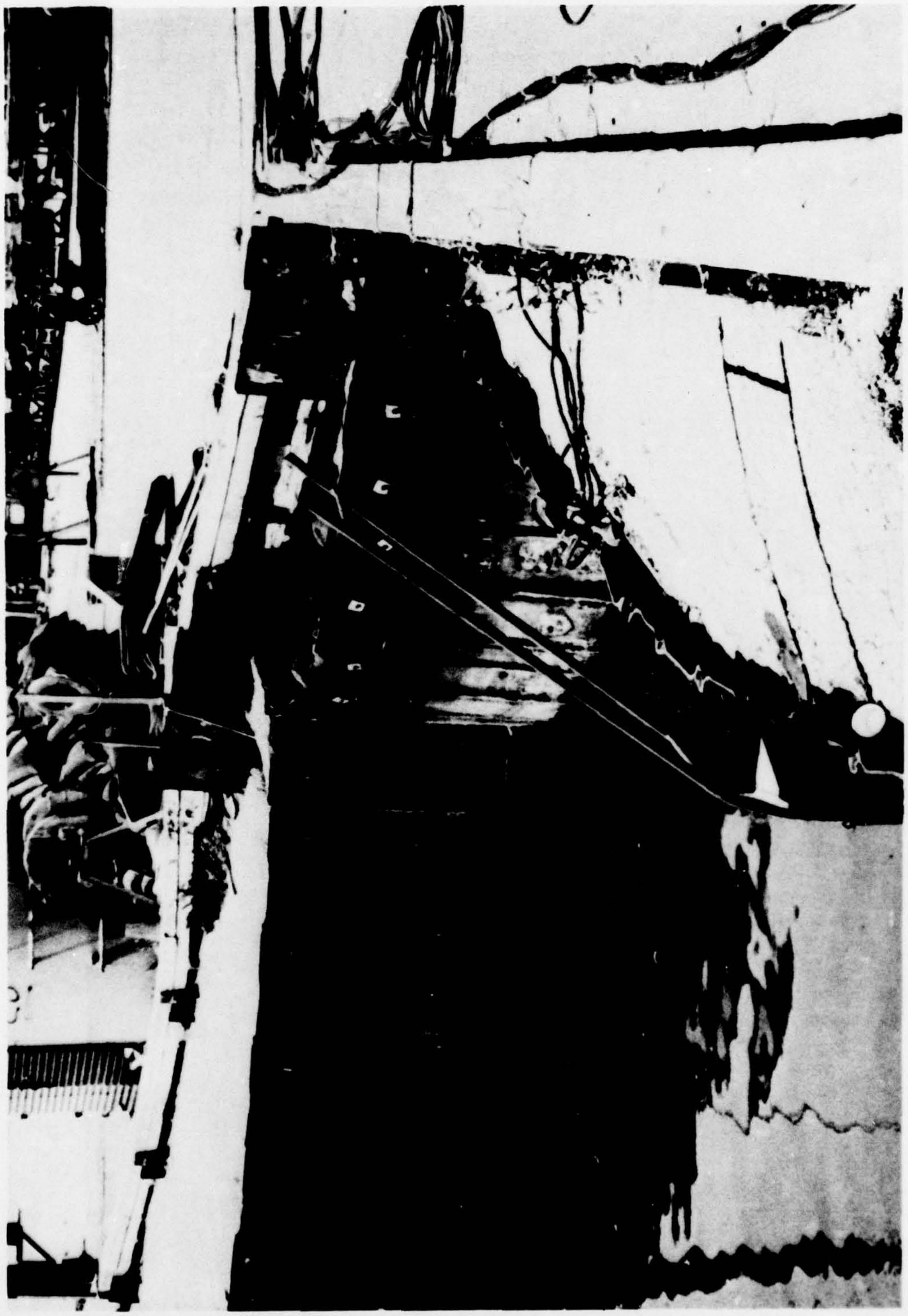

Figure 7. Sheet pile cells at Site 2.

Figure 8. Gunite-encased wood piles supporting Pier No. 1.

Table 1. Summary of Sonic Measurement Data

Pile No.	Type of Pile	Location	Length (ft)		Measured Sonic Travel Time (ms)	Length Determination		Remarks
			Design	Driven		Assumed Velocity (fps)	Equivalent Length (ft)	
1	steel sheet	Site 1	76	–	–	–	–	Poor coupling to exposed pile top.
2	steel sheet	Site 1	76	–	0.88	16,000 17,300	70.5 76	True pile length might be less than design. This velocity seems high.
3	steel sheet	Site 1	76	–	–	–	–	Poor coupling to pile.
4	steel sheet	Site 1	76	–	0.88	16,000 17,300	70.5 76	Same as Pile No. 2.
5	steel sheet	Site 1	76	–	–	–	–	Poor coupling to pile.
6	steel sheet	Site 2	76	–	0.96	16,000	77	Actual pile length unknown.
7	steel sheet	Site 2	76	–	0.96	16,000	77	Similar to Pile No. 6.
8	steel sheet	Site 2	76	–	–	–	–	Pile under concrete; poor coupling.
9	steel sheet	Site 2	76	–	0.96	16,000	77	Pile under concrete; ignore concrete thickness.
10	steel sheet	Site 2	76	–	0.96	16,000	77	Same as Pile No. 9.
11	steel sheet	Site 2	76	–	0.96	16,000	77	Same as Pile No. 9.

Table 1. Continued

Pile No.	Type of Pile	Location	Length (ft)		Measured Sonic Travel Time (ms)	Length Determination		Remarks
			Design	Driven		Assumed Velocity (fps)	Equivalent Length (ft)	
12	timber, gunite	Site 3	–	92	1.29	14,300	92	Velocity appears slightly high.
13	timber, gunite	Site 3	–	95	1.21	15,700	95	Velocity appears too high.
14	timber, gunite	Site 3	–	92	1.26	14,600	92	Same as Pile No. 13.
15	prestressed concrete	Site 4	–	76.5	1.13	13,000 13,500	73.5 76.5	Transducer in contact with p. 6 top.
16	prestressed concrete	Site 4	–	76.5	1.13	13,000 13,500	73.5 76.5	Same as Pile No. 15.
17	prestressed concrete	Site 4	–	126	–	–	–	Data unreliable; insufficient return of sonic energy.
18	prestressed concrete	Site 4	–	126	–	–	–	Data unreliable; excessive attenuation.

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